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AUTHOR(S): J. Douglas Balcomb

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University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
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PERFORMANCE ESTIMATION USING CORRELATION METHODS*

Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

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J. Douglas Balcomb

INTRODUCTION

It is now generally accepted that computer simulation analysis using thermal-network type of mathematical representations of the energy flows is an accurate method of predicting the performance of passive solar buildings. The analysis is generally done using hourly solar and weather data. This is fine if the designer has the computer, the capability, and the inclination to take this approach. But even under the best of circumstances it is costly and time consuming. Most designers ask for simpler techniques which are amenable to analysis using hand calculators in which estimates can be generated in a few minutes. Correlation techniques have emerged as a reasonable procedure which meet these requirements and give reasonable accuracy.

CORRELATION METHODS

In a correlation technique one seeks to relate the results in terms of one or more correlating parameters (generally dimensionless). Success is much more likely if the correlating parameters chosen preserve some essence of the overall physics governing the energy balances. The F-chart technique, which was developed at the University of Wisconsin for active solar systems, is an example of a correlation technique. In this case two correlating parameters were used. Independently, researchers at the Los Alamos Scientific Laboratory developed the Solar Load Ratio method (SLR method) which utilizes one correlating parameter.

These two methods have two things in common. They both use monthly weather data to predict monthly performance. A month has been found to be a particularly convenient time interval, being long enough that statistical variations tend to average out somewhat and short enough so that the basic weather statistics are stationary. Furthermore, only eight to twelve calculations are required in order to predict annual performance. The prediction of monthly performance leads to relatively high standard errors (±8%, typically) but annual performance is predicted with a standard error of only ±7%, typically. This is perfectly adequate for design purposes, being significantly less than the year-to-year variation which can be anticipated.

A second common feature of both F-chart and the SLR technique is that the correlations are done using "data" developed from hour-by-hour computer simulations. In the case of F-chart, the TRNSYS code was employed and for the SLR correlations the LASL SOLAR code was employed (these codes have been shown to give essentially identical results). Thus the correlation techniques are a second-generation analytical procedure, intended to give reasonably good correspondence with the simulation analysis. Their results are intrinsically no better than those obtained from simulations. The correlation techniques, however, are at least two orders of magnitude easier to use in terms of the computing power and the computing time required.

THE SOLAR LOAD RATIO TECHNIQUE APPLIED TO PASSIVE SYSTEMS

The SLR method has been applied extensively to a variety of passive systems. A different correlation is required for each different type of passive system. Thus far, direct gain, Trombe wall, water wall, and sunspace configurations have been studied. The results are being fairly widely used within the passive solar design community. The method is the basis for the design techniques described in the DOE Passive Solar Design Handbook, Volume II, Passive Solar Design Analysis.[1] A variety of hand held calculator and microcomputer routines have been written using the methodology. The SLR method depends on the use of a single correlating parameter (SLR) defined as follows:

SLR = (solar absorbed)/(net reference load)

As mentioned, the correlation time is one month so that each of the parameters in the above equation are for a one month period. Both the numerator and denominator of SLR are in energy units so SLR itself is dimensionless. Physically it relates the monthly solar energy available to the building to the net load which would be experienced by a comparable building without the passive solar element.

The parameter which is correlated is the solar savings fraction, SSF, defined as follows:

SSF = 1 - (auxiliary)/(net reference load)

The definition of the terms used in these two relations is important, but it is not the purpose here to discuss this in detail. The various terms are defined in the Passive Solar Design Handbook where the distinctions between various ways of estimating load are discussed. The key point is that the solar savings fraction is intended to identify the savings due to adding a particular passive solar element on a building. The net

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reference load is the heating requirements of a comparable non-solar building, that is, a building which is otherwise identical but without the passive solar element. Presumably the solar element would be replaced with a normal wall with the normal complement of windows.

In developing the correlations, a functional form was used which allows the selection of four different coefficients. These were adjusted in order to obtain a least-square error in the annual solar savings fraction.

Typically the correlations are done using hour-by-hour calculations from many different cities with four different values of building load coefficient in each city. This gives a reasonably diverse ensemble of data points. The standard deviation of the error in prediction of solar savings fraction, compared to the hour-by-hour simulations, is typically about 3 to 4%.

REFERENCE DESIGNS

The hour-by-hour simulations which are used as the basis for the correlations are done with a detailed model of the building in which all of the different design parameters are specified. The only design parameter which is changed is the ratio of the glazing area to the building load coefficient of the building (the Load Collector Ratio, LCR). Typically about four different values of LCR were chosen so that the correlation should adequately reflect variations in this key parameter.

The correlations do not allow the designer to estimate performance variations due to changes in any of the many other design parameters. Thus the correlations relate only to the reference design used in the simulations.

In order to overcome this difficulty, sensitivity calculations have been done using the hour-by-hour simulation codes. The procedure is to perform a series of year-long simulations for different values of one of the design parameters, holding all other parameters at the reference level. These results are generally presented in graphical form and allow the designer to see the effect of changing one particular design parameter. This procedure is followed for each of the different design parameters. A major part of the Passive Solar Design Handbook is taken up with such sensitivity studies for the direct gain and thermal storage wall systems.

It is certainly possible that one could re-do the entire correlation procedure for different values of design parameters in order to study the effect on the correlation curves of changing that parameter. This has generally not been done because it would be incredibly tedious and require an unreasonable amount of computer time.

ATTACHED SUNSPACES

In a recent publication[2] McFarland and Jones have given correlations for attached sunspaces. These results indicate that a sloping glazing (about 50 degrees) is much more effective than vertical, that heating performance is improved by using opaque insulated end walls rather than glazed end walls, and that overall performance in heating the attached building is very comparable to that of a Trombe wall.

As an example of the correlation results, the following graphs give the simulation results (Fig. 1) and correlation accuracy (Fig. 2) for one reference design, the case of an attached sunspace with sloping glazing (50 degrees), masonry thermal storage between sunspace and house, opaque end walls, and no night insulation.

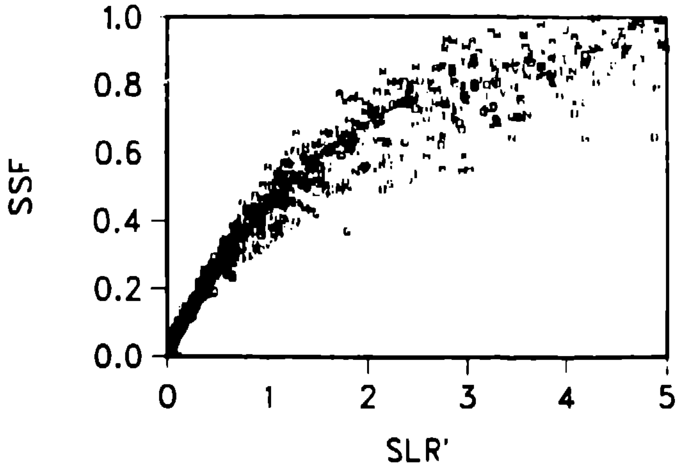

Fig. 1. Monthly SSF vs SLR'. See Ref. 2. for the definition of SLR' as it applied to sunspaces.

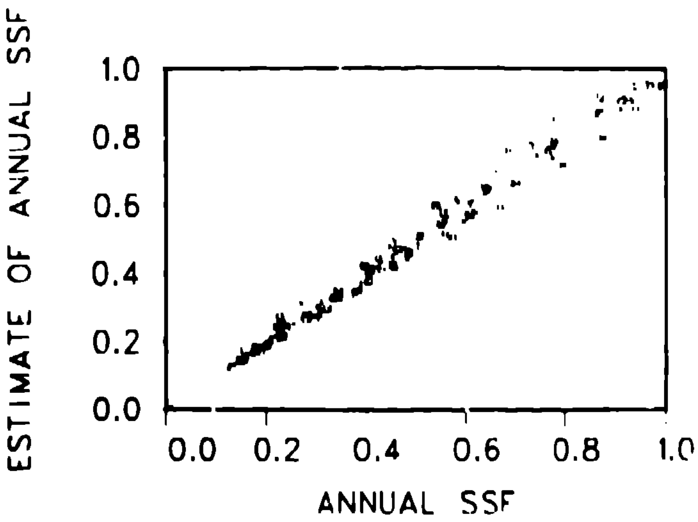

Fig. 2. Comparison of annual SSF estimated by this method and calculated by simulation. The standard deviation of the error is [illegible] over an ensemble of four LCR's each in [illegible] cities.

More recent results, as yet unpublished, indicate even better performance for a "semi-enclosed" sunspace, that is, a geometry in which the house wraps around the sunspace enclosing the east and west ends. This geometry provides the highest performance of all passive solar geometries studied to date by LASL.

PERFORMANCE TABLES FOR PARTICULAR LOCATIONS

Since the correlation curves are developed using weather data from a variety of different locations, these curves can be used in locations which have a climate type encompassed by the original grouping of cities. However, an annual solar savings fraction calculation involves summing up the results of twelve monthly calculations. For a particular city the results depend only on the ratio of building load to collector area (LCR), on the system type, and on the temperature base used in the calculation of the degree days. Thus it is possible to make up tables for a particular city which relate the solar savings fraction to the LCR for the various systems, assuming one particular base temperature. These tables could be re-done for various base temperatures. These tables are much easier to use than the SLR correlations.

LCR tables have been made up for 216 different locations in the U.S. and southern Canada based on the SOLMET weather data. These are published in the Passive Solar Design Handbook, Appendix F, for direct gain and thermal storage wall systems. These tables form the basis of a simplified design procedure described in the Handbook.

As an alternative to presenting the SSF results in terms of LCR, many people have expressed a preference for using the reciprocal, collector load ratio, CLR = 1/LCR, as the independent parameter. Fig. 3 shows the performance of 4 attached sunspace options in Dodge City plotted vs CLR (sq ft-DD/Btu) showing the comparison between the results of hourly simulations (solid curves) and the estimates using the SLR correlations (dashed curves). The geometry is the same as for Figs. 1 and 2, with I.E. for insulated end walls and G.E. for glazed end walls.

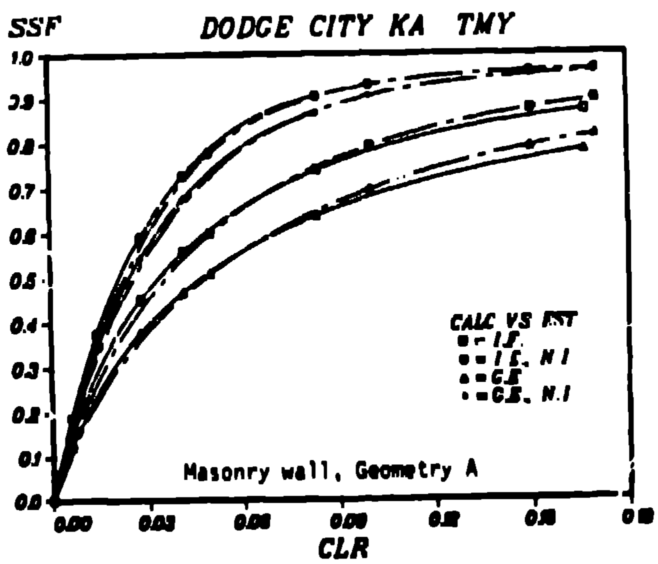

Fig. 3. Comparison of simulation and correlation results for an attached sunspace in Dodge City.

MIXED SYSTEMS

The correlations have all been done for a single system type such as direct gain or Trombe wall. The results show that the different systems tend to behave in very similar fashion with one notable exception -- direct gain without night insulation. There is, however, a very marked difference between the performance of all three system types depending on whether night insulation is employed or not. A curve has been developed which provides a methodology for dealing with night insulation other than the value R9 used in the reference design. This curve is Fig. E-7 in the Passive Solar Design Handbook.

A simple methodology has been developed for dealing with mixed systems. The technique treats the house building load coefficient as if it were divided into two portions in the same ratio as the relative glazing areas of the two passive system types. This amounts to the simple assumption that each of the system types serves a portion of the load with no exchange of heat across an imaginary boundary within the house. Normally one would expect that transfers which do take place would be beneficial and therefore the calculations based on this assumption might be somewhat conservative. There have been no hourly computer simulations performed to determine the exact degree of the underestimate.

In the meantime it would seem to be quite reasonable to deal with mixed systems using the methodology described in the Passive Solar Design Handbook.

PERFORMANCE VARIATION DUE TO LIVING HABITS

All of the simulation analyses used to develop the correlations are based on a building which is used in a very specific and regular manner. The auxiliary heating thermostat is assumed to be set at a particular fixed level (generally 65 F). A 10 F floating band is assumed. If the temperature in the house exceeds the thermostat setting by more than 10 F then it is assumed that the excess energy is vented so as to maintain the temperature less than or equal to the upper setting. This energy is not stored and is therefore lost.

It is well known that the manner in which the house is operated greatly affects the energy consumption. The thermostat setting for auxiliary heat is by far the most important effect. This shows up clearly in the sensitivity analyses. For example, a thermostat setting of 70 F (which might correspond to a degree day base temperature of 65 F, accounting 5 F for the effect of internal generation) might result in an auxiliary heating requirement of 8.2 million Btu/year for a [illegible] sq ft house in Dodge City, Kansas. This is a house designed for 78% solar savings fraction (the example problem in the Passive Solar Design Handbook). If the thermostat were set at 75 F instead, the auxiliary heating would be 14.2 million Btu; or, if the thermostat was set at 60 F, the auxiliary heat needed would be about 2.2 million Btu/year.

Therefore, in interpreting the results from monitored buildings, or in predicting the performance of new buildings, one must be very careful to specify the operating conditions.

Other operating characteristics of the house can also be important, such as, 1) if movable insulation is provided for the house, then it is important to know how it is operated, 2) a family with many small children may experience larger infiltration due to multiple door openings, 3) a house with doorways connecting between the living areas and a sunspace might be much more comfortable if some attention is paid to the appropriate opening and closing of these doors.

DECIDING BETWEEN CONSERVATION AND PASSIVE SOLAR OPTIONS

Every good passive solar designer knows that energy conservation must be a cornerstone of the building design. But at some point the trade-off between additional energy conservation and passive solar collection aperture must be addressed. If a handy method is available for estimating performance, then this trade-off can be done in an analytical way. For example, if the correlation techniques can be incorporated into a hand held calculator or microcomputer routine, then the designer can obtain very quick turn-around in the calculations, and the trade-off between conservation and solar options can be easily and quickly assessed.

A simple technique has been developed which can be used to determine the optimum mix between conservation and solar strategies.[3] In order to obtain an answer, the cost characteristics of both the passive solar aperture and the energy conservation features are needed. This information will generally be in the form of the cost per R per sq ft for the wall and ceiling insulation, the cost per additional glazing for windows, the cost of reducing infiltration (including the cost of adding an air-to-air heat recovery unit if needed) and also the cost per sq ft for the passive solar collection aperture. Given this information the method provides simple equations which can be used to trace out the optimum-mix line for a particular locale. This will provide information to the designer early in the design process to serve as a guide in the decision making.

CONCLUSIONS

Correlation methods of prediction have advantages in greatly simplifying the time and complexity of performance predictions but are severely constrained in the number of variables which can be considered. Their accuracy is generally adequate for design purposes provided they are applied to buildings which correspond reasonably closely to the reference designs used in developing the correlations. The most simplified correlation procedures (such as the SLR method) are amenable to use with hand calculators, especially if pre-calculated tables are available corresponding to the weather data for the location of interest. When reporting the results of these calculations, the designer should be especially careful to specify the range of validity of the analysis, especially as pertains to both operating characteristics and design parameters.

Correlation techniques are especially amenable to use in microcomputer routines which can be used in a design office. Very quick answers can be obtained during the schematic design and design development phases of a building to aid in deciding between different design options. This would include trade-offs between various conservation options and passive solar options.

ACKNOWLEDGEMENTS

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